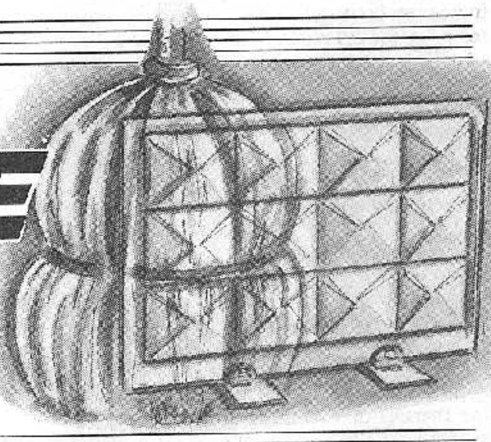
Constructional Project

MULTI-PURPOSE THERMOSTAT



ALAN WINSTANLEY

An adaptable design for precise control of electric heaters. Useful in domestic, horticultural, photographic, aquatic applications and more. Full 13A 250V rating.

TEMPERATURE control is just one area where electronics excels over its electromechanical counterparts. Mechanical bi-metallic strips are often used in heating systems not requiring a particularly fine degree of temperature control, for instance in tropical aquaria an immersible bi-metallic strip thermostat is the usual means of sensing the water temperature since it is cheap to implement and is reasonably reliable. The initial setting up, however, is often a matter of trial and error because these devices are generally completely uncalibrated and the only way to know whether you've got it right is to try it and see – and hope that the fish agree!

In other domestic applications a bi-metallic strip may find its way into a typical central heating thermostat, and refrigerator or electric fire temperature controls. In the case of a fan or convector heater thermostat, for instance, the control may be calibrated with just an arbitrary scale and secondly, there is almost always a proportion of "overshoot" where the temperature has to reach a peak before the bi-metallic strip will switch off the heater.

Then the temperature may have to fall to an undesirably low level before the heater switches in again. Therefore the control might well be set with the minimum required temperature in mind, paying scant attention to the unnecessary temperature peaks and surges which may occur before the bi-metallic thermostat turns the fire off. Hence, you either freeze or fry!

Another problem with electromechanical thermostats is their tendency to "waver" at the desired setting, resulting in a second or two of buzzing and contact arcing as the bi-metallic strip trips over. Sometimes a magnet is included on the strip to help guard against this, to accelerate the movement of the contacts when they switch over.

APPLICATIONS

It's a simple matter to overcome all of these disadvantages with an electronic thermostat such as the one to be described here. This general purpose unit can be adapted to suit the reader's specific requirements. It was designed to be safe and reliable to construct, whilst keeping a keen eye on cost.

It has a full 13A 250V rating which enables it to control a load of up to 3kW (3,000 watts).

By fitting a temperature sensor of suitable design, it can be used to detect both air and liquid ambient temperatures. This makes it useful for:

- General domestic applications (electric fires, space heating etc.).
- Horticultural use (greenhouse heating, propagator and nursery bench temperature control).
- Photography (dish warming, developer process control).
- Printed circuit board (p.c.b.) production etchant temperature control.
- Tropical aquaria – fishtank heating.
- Homebrewing – fermentation control.

An extra feature of this design is the inclusion of an optional "hysteresis" control. This permits the user to adjust the difference between the high and low temperature switching points, which then allows further control over the temperature accuracy.

This means that the operating band of the thermostat can be narrowed or widened somewhat, which may help to compensate for the thermal "inertia" of the heating system: a larger inertia means more stored warmth in the heater, producing a temperature overshoot even after the heater has switched off. The hysteresis control feature could, however, be omitted if necessary.

CIRCUIT DESCRIPTION

The complete circuit diagram of the Multi-Purpose Thermostat is shown in Fig. 1. This is a straightforward design centred around an operational amplifier i.c. IC3, configured as a Schmitt trigger. It is powered from a mains-derived regulated 12V d.c. rail. A high-stability adjustable shunt regulator (IC2) is set to provide an accurate reference voltage for the op.amp, which compares a temperature-dependent signal against this reference and operates a heavy duty relay to turn the mains load on and off accordingly.

A thermally-sensitive resistor or thermistor R9 forms the temperature sensor for this unit. In order to economise, a readily available bead thermistor was selected rather than a glass bead type, which although more accurate is both more expensive and quite delicate to handle.

The thermistor has a negative temperature co-efficient (n.t.c.) which implies that its resistance falls when its temperature increases. It's usual to specify the thermistor resistance at a given temperature: a 4k7 at 25°C bead is used.

This is located remotely from the main thermostat and is connected by a 3·5mm jack plug and socket, PL1/SK2. Capacitor C4 helps reduce any noise picked up on the connecting cable. By suitably mounting the thermistor, it can be adapted to sense either liquids or ambient air temperatures, see later.

Along with Temperature control potentiometer VR1 and resistor R5, the thermistor forms a potential divider which is connected to the non-inverting (+) input, pin 3, of the op.amp IC3, which has a high impedance MOSFET input. When the thermistor's temperature increases, its resistance falls and so the non-inverting input voltage falls also.

The op.amp amplifies the difference between the voltages of the non-inverting and inverting input (pins 3 and 2 respectively). If the + input is greater than the − input then the output swings "high". Conversely, should the − input be greater than the + input then the output will move negatively "low".

Because a single rail supply is used here rather than a split supply, the output pin can only switch either to the positive rail or to 0V, depending on the polarity of the two input voltages. In this mode the op.amp is actually operating as a comparator.

REFERENCE VOLTAGE

The inverting (−) input is firmly clamped at a fixed reference voltage. This is set for precisely 6V d.c. (half the rail voltage) and is generated by IC2, a TL431 adjustable shunt regulator.

This is quite a handy device to become acquainted with, and its basic principle of operation is shown in Fig. 2. The device

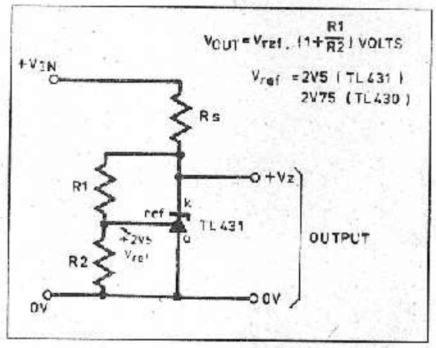


Fig. 2. Operation of the high stability TL431 adjustable shunt regulator.

has three pins, namely anode (a), cathode (k) and a third "reference" (ref) terminal. The TL431 has its own temperature-compensated "bandgap" reference which is highly stable and contributes to the great accuracy of the component – important in a thermostat application where the reference voltage should not drift unduly with temperature.

The TL431 reference voltage is 2·5V which appears between the anode and reference pins as shown. A potential divider consisting of resistors R1 and R2 is used to determine the output voltage of the device. It's preferable to allow a 1mA current to flow through the potential divider and the designer allowed a further 5mA forward current to flow through the TL431 itself.

The formula is:

$$V_Z = V_{ref}\left[1+\frac{R1}{R2}\right]$$

To generate a 6V "Zener" output voltage, a little equation solving produced values of 4k7 and 3k3 for R1 and R2 respectively. Happily, these values are readily available in the E12 series thus no special precision resistors are needed.

A series current limiting resistor Rs is also needed which is calculated in the same way as that for an ordinary Zener diode. If we assume a supply rail of 12V d.c., and a Zener output of 6V, then with a total of 6mA (1mA + 5mA) flowing through the series resistor, a 1k value is fine.

DYNAMIC RESISTANCE

This reference circuit has several key advantages over an ordinary Zener diode. Apart from the fact that the output voltage can be controlled precisely with external resistors, it has a much greater temperature stability (typically 50 parts per million per degree C.) and also has a much lower internal resistance.

The "dynamic" resistance of a standard Zener diode could be some 40 ohms or more, which produces an unwanted error voltage when the Zener current increases (the resistance causing an undesirable "internal" voltage drop within the Zener diode). Even the dynamic or "slope" resistance of a 1N821 temperature compensated Zener is 15 ohms, for instance. The dynamic resistance of the TL431 is only 0·2 ohms, so the reference output is largely independent of the current flowing through the component.

The result is a highly stable reference voltage which is used to clamp the inverting input of the op.amp IC3 at 6V. Hence, whenever the voltage at pin 3 is greater than 6V, the op.amp output switches high. This turns on the transistor switch TR1 and completes the circuit to the power relay RLA, also the l.e.d. D7 will illuminate whenever the relay is switched on. Diode D6, as usual, guards against back e.m.f. from the coil when the relay switches out.

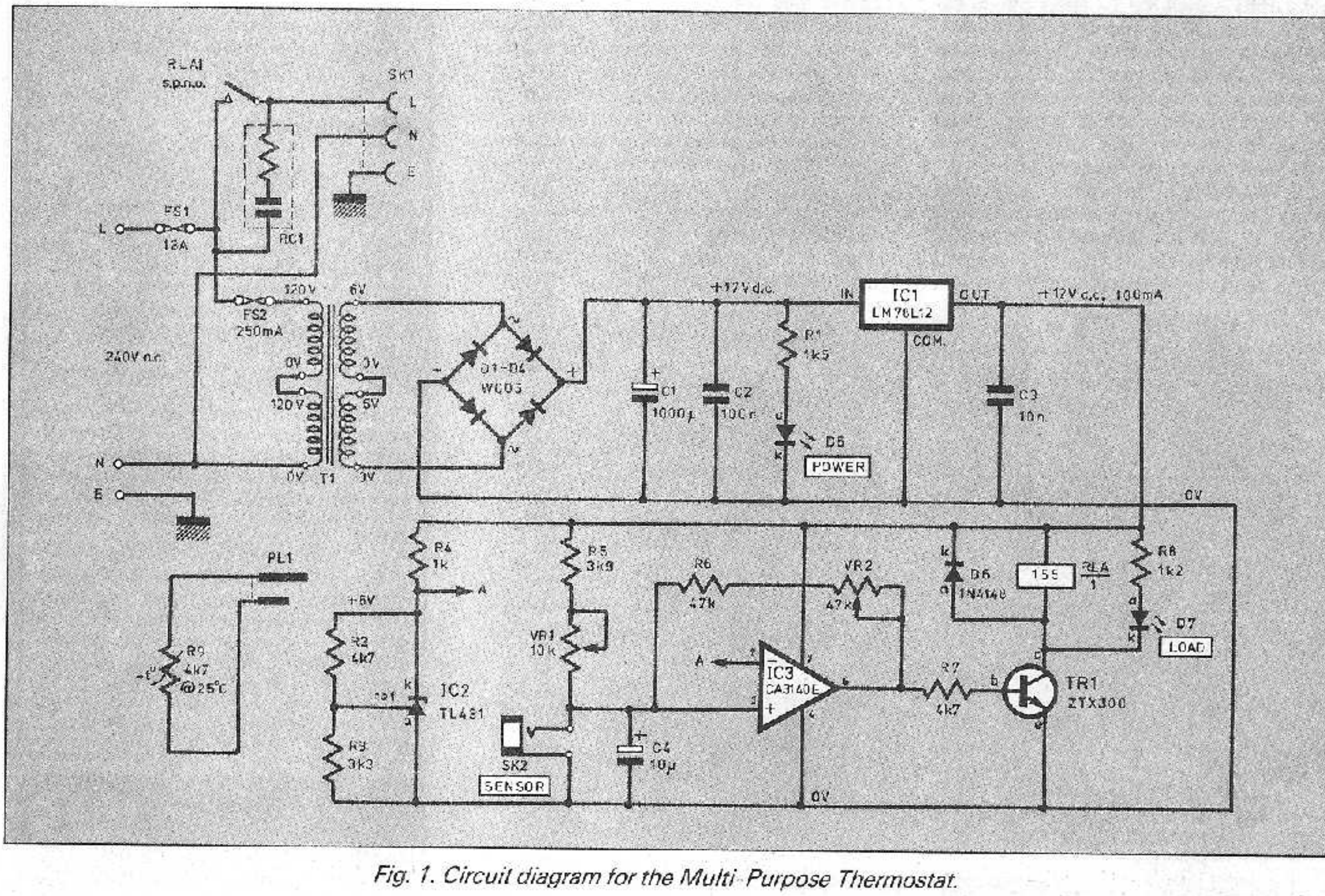


Fig. 1. Circuit diagram for the Multi-Purpose Thermostat.

HYSTERESIS

A potential drawback with this arrangement is that it is very sensitive, and the op.amp will amplify the tiniest difference between its two inputs and switch the output high or low. With an input signal which is relatively slow-moving, there are often occasions when the circuit may seem to "jitter" just on the switching point. This can be very undesirable when switching mains loads, and can be overcome by converting the circuit into a clean "snap action" Schmitt trigger.

To do this, a feedback arrangement is introduced with VR2 and R6. This effectively causes the switching point to have two levels – a higher and a lower set point with a small difference in between called the "hysteresis."

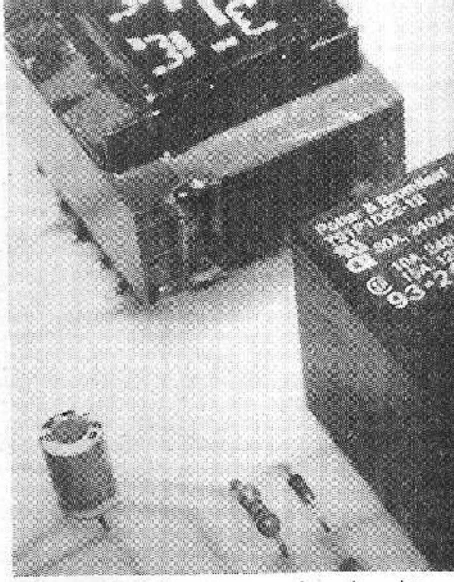
Now the circuit is no longer able to "jitter" at the set point: instead, the temperature must reach a particular level to switch the heater off, and then it must fall to a lesser temperature before the heater can switch on again. By making this hysteresis variable, it's possible to adjust the operating characteristics of the thermostat so that you can compensate for any temperature overshoots. This feature could be left out if desired, see later.

Turning to the power supply section, mains voltage is stepped down by transformer T1 to 12V a.c. which is then rectified and smoothed by bridge rectifier D1-D4 and capacitor C1, to produce approximately 17V d.c. This is fed to a standard three terminal 12V 100mA fixed voltage regulator IC1 and forms the power rail for the electronics. An l.e.d. D5 placed before the regulator, lights as a "Power On" indicator.

RELAY

The specified relay has an important constructional feature in that it is very heavy duty (rated up to 30A) but is extremely economical, and most importantly although it is p.c.b. mounted it has push-on terminals for direct access to the contacts. A snubber network RC1 was also used to protect against contact arcing, which would be more evident when inductive loads such as fan heaters are switched.

The single-pole contacts of the relay switch the Live mains feed which is then passed to SK1, a standard 13A mains socket. Finally, a 13A fuse FS1 protects against faults in the load and FS2 is a low current quick blow fuse to protect against transformer faults etc. No mains on/off switch was included but guidance notes are given at the end should you wish to fit one.



Close-up of the power relay showing the push-on "spade" terminals accessible from the top.

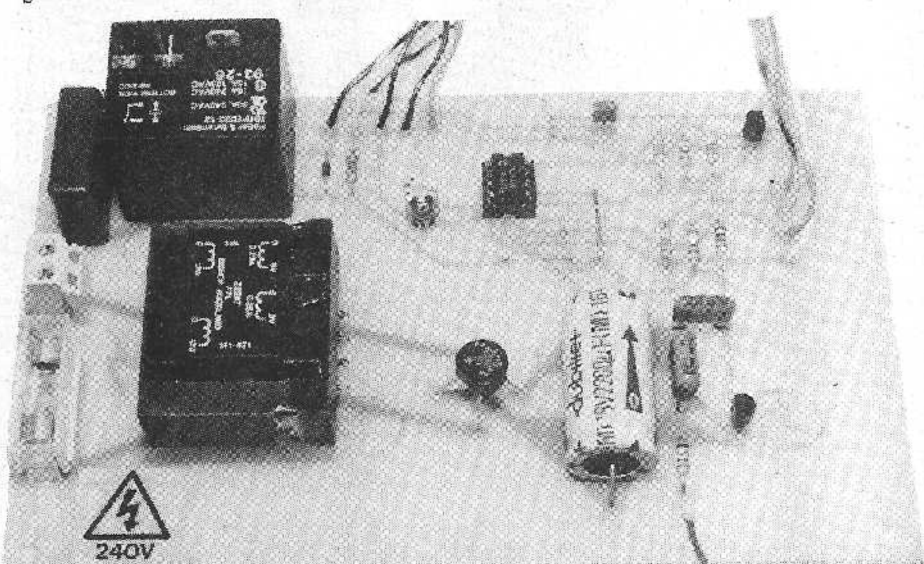
CONSTRUCTION

This project contains a mixture of both mains a.c. and low d.c. voltages. The unit was designed to ensure that construction was kept as simple and as safe as possible. If you are an inexperienced constructor then you must follow the details closely or seek help from a qualified person.

Do not substitute components but use those recommended in the Components List and you should have no difficulty in producing a safe and trouble free project. The use of an ELCB/RCD is strongly recommended during the initial testing and calibration stages.

In order to simplify construction, the circuit was constructed on a single-sided printed circuit board (p.c.b.). The board measures 160mm × 100mm and is available from the *EPE PCB Service*, code 931, or it can be home-made using the p.c.b. foil pattern as a guide in the usual manner.

The p.c.b. carries all of the electronic components apart from the panel mounting parts. Fig. 3 shows the details of the component layout on the board and the full size copper foil master. There are four 3mm clearance holes on the p.c.b. to accommodate the fully insulated mounting



Layout of components on the completed printed circuit board.

COMPONENTS

See SHOP TALK Page

Resistors

R1	1k5
R2, R7	4k7 (2 off)
R3	3k3
R4	1k
R5	3k9
R6	47k
R8	1k2
R9	bead thermistor, 4k7 at 25°C

All 0·25W 5% carbon film, except R9

Potentiometers

VR1	10k rotary carbon, lin. 0·4W
VR2	47k rotary carbon, lin. 0·4W

Capacitors

C1	1000µ axial elect. 25V
C2	100n polyester
C3	10n polyester
C4	10µ radial elect. 16V

Semiconductors

D1-D4	W005 50V PIV 1A bridge rectifier
D5	3mm red l.e.d.
D6	1N4148 signal diode
D7	3mm green l.e.d.
TR1	ZTX300 *npn* transistor
IC1	LM78L12ACZ, 12V 100mA regulator
IC2	TL431 adjustable shunt regulator
IC3	CA3140E CMOS op.amp

Miscellaneous

T1	0V-6V, 0V-6V 3VA p.c.b. mounting mains transformer
SK1	panel mounting 13A mains socket
SK2	3·5mm jack socket
PL1	3·5mm jack plug
RLA	155 ohm 12V 30A mains single-pole p.c.b relay
RC1	mains contact suppressor
FS1	13A mains fuse
FS2	250mA 20mm fuse with p.c.b. holder

Printed circuit board, 100mmx160mm, available from the *EPE PCB Service*, code 931; 8-pin d.i.l. socket; l.e.d. mounting clips (2 off); plastic box with aluminium panels 231mm x 181mm x 77mm; two-way p.c.b. screw terminal (TB1); 3-way 13A mains screw terminal, with built-in 1¼in. fuseholder (TB2); 13A 3-core cable and mains plug, materials and screened single core cable for temperature sensor to suit, 6A and 13A mains interconnecting wire; 0·25in. female crimp blades (2 off); cable restraint; 10mm crimp ring terminal; control knobs (2 off); fully insulated p.c.b. M3 mounting hardware; solder, hook-up wire etc.

Approx cost guidance only **£29**

excluding case

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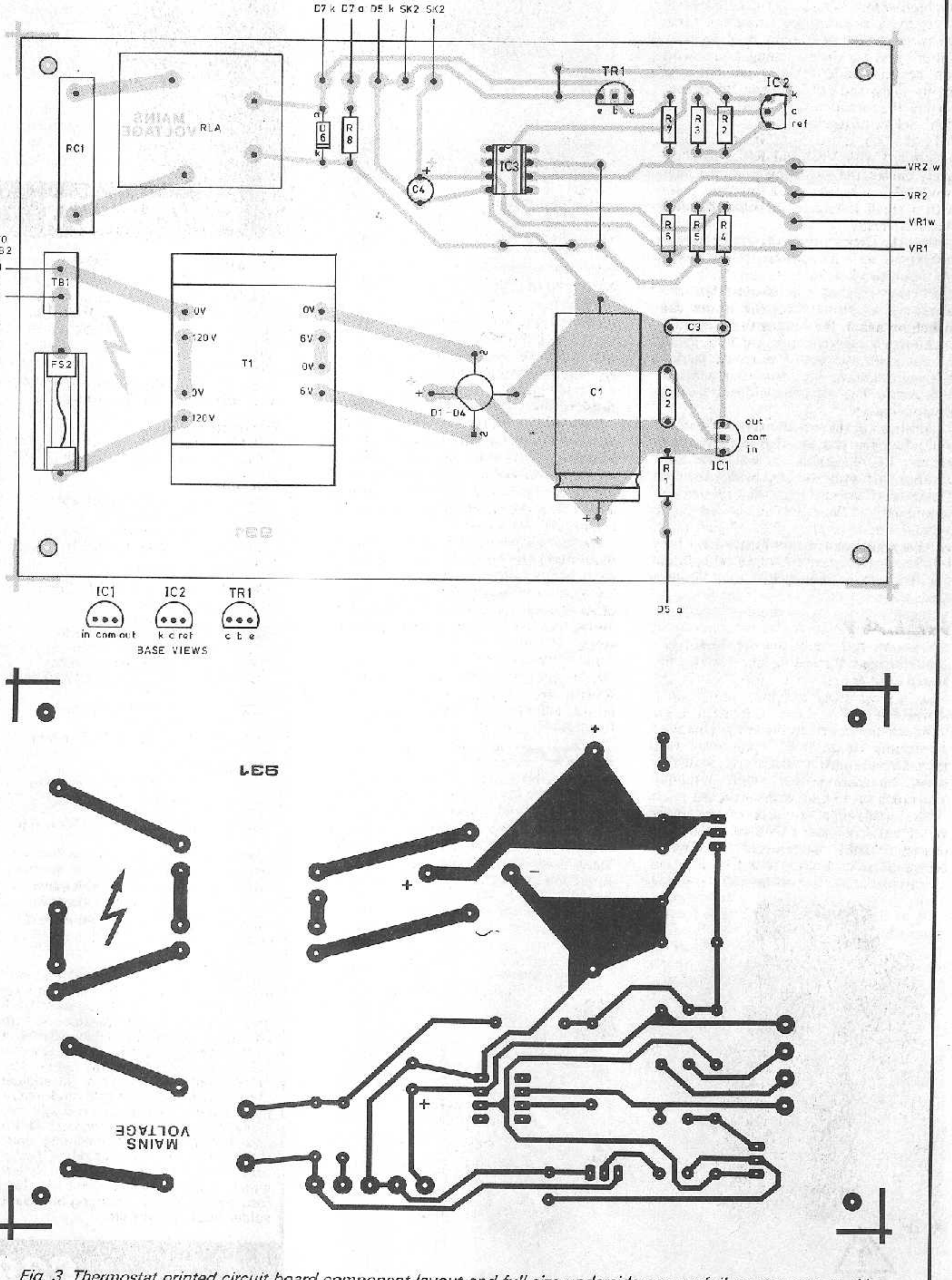


Fig. 3. Thermostat printed circuit board component layout and full size underside copper foil master pattern. Also shown are the pinout details for IC1, IC2 and transistor TR1.

Front panel layout and lettering.

hardware. The empty p.c.b. can be used as a template to mark out the drilling centres on the chosen case.

For convenience it is best to commence assembly by fitting the smallest and fiddliest parts first, finishing with the heaviest and largest components. There is plenty of space on the board, so start by soldering into place the three tinned copper link wires, then continue with the discrete components.

An 8-pin d.i.l. socket may be used for IC3, but do not fit the static-sensitive op.amp into position yet. Continue with the power supply section, noting that the polarities of the bridge rectifier D1-D4 and the smoothing capacitor C1 are absolutely ***critical***.

Also you must observe the polarity of the semiconductor devices carefully as these are likely to be damaged if their connections are reversed (it's one of the few ways you can destroy an overload-protected i.c. such as a regulator). Pinout connections are shown separately for the TL431,12V regulator and transistor, and must be followed closely.

RELAY

As explained earlier, the relay RLA is an interesting choice (see Components List) because although it is a p.c.b. mounting type, it has heavy duty contact terminals accessible on top, as well as via the p.c.b. This means that it is not necessary for the p.c.b. to carry a full 13A load, instead the load is routed to the relay directly through heavy gauge connecting wire.

In fact, only the relay *coil* is driven through the p.c.b. foil pattern and separate 13A wire will be used for the load connections which are taken straight off the relay housing (see photos) via 0·25in. blades – a very neat solution to an age-old problem.

Whilst the main contacts also have solder pins, these are soldered to the board just to make the mounting of the relay more secure, and to connect the snubber RC1.

Mains input to the printed circuit board is effected via a two-way screw terminal block TB1 but this only carries a moderate current for the thermostat circuit. It does not carry the heater load current. Fuse FS2 is a p.c.b. mounting type which on the prototype has a protective clip-on cover.

Next, quickly fit the op.amp IC3 into its d.i.l. socket, using Fig. 3 as a guide, and taking any anti-static precautions necessary: it's safest to discharge any static away from your body through an Earthed point prior to handling the chip.

Finish off by soldering the mains transformer into place. It will only fit one way round but ensure that it is flush against the p.c.b. before soldering.

Having fitted all parts to the board, check the soldering very carefully, looking for signs of dry or incomplete joints, or stray whiskers of solder shorting adjacent copper pads. You may wish to finish off by spraying the copper foil with a coat of p.c.b. lacquer. Normally this can be through-soldered when connecting the flying leads.

HOUSING

These days, the enclosure is often amongst the most expensive of a project's components and it pays to compare sizes and shop around; alternatively you might consider saving money by producing a box yourself from suitable materials. The prototype was constructed in a plastic housing which had attractive front and rear aluminium panels coupled together with pressed steel members. It appeared to be the most competitively priced box for the required size.

The dimensions are primarily determined by the size of the mains socket which is fitted to the rear panel, also the "footprint" of the box must accommodate the p.c.b. together with a heavy duty 3-way terminal block (see photographs).

After some consideration the prototype used a plastic case no. BIM 3503 measuring 231 × 181 × 77mm, sourced from ElectroValue. This box was (only) just high enough to carry the mains socket as shown in the photographs.

Ventilation slots are also formed into the rear panel and plastic base though these are superfluous in this design. It also had tilt feet as a finishing touch. Any other suitable case of appropriate dimensions could be used but one with metal panels will facilitate good earthing, and aluminium is a more easy to work than steel.

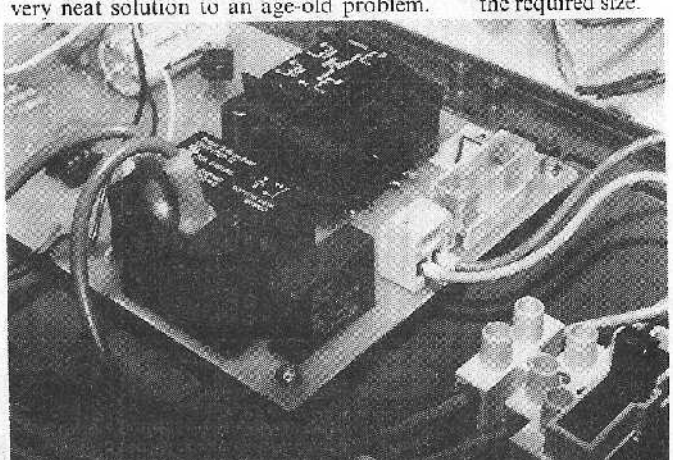
The base needs preparing to accept the p.c.b. mounting hardware if you haven't already done so earlier. The front panel is punched to carry the two potentiometers and two light emitting diodes (l.e.d.s): a 10mm or 3/8in Q-Max chassis punch will make light work of the pot. mounting holes whilst the l.e.d.s can be supported with plastic lens-clips or similar, of appropriate size. The prototype used 3mm l.e.d.s in transparent clips for an attractive finish.

After carrying out the metalwork, the panel can be enhanced with rub-down lettering which is now widely available in the High Street in many typefaces. If desired, the two rotary controls can also be embellished with rub-down "scales" such as those provided by Alfac (their part no. EC802). These vastly simplify the accurate marking out of the dials. Finally, spray on several coats of protective lacquer before turning to the rear panel.

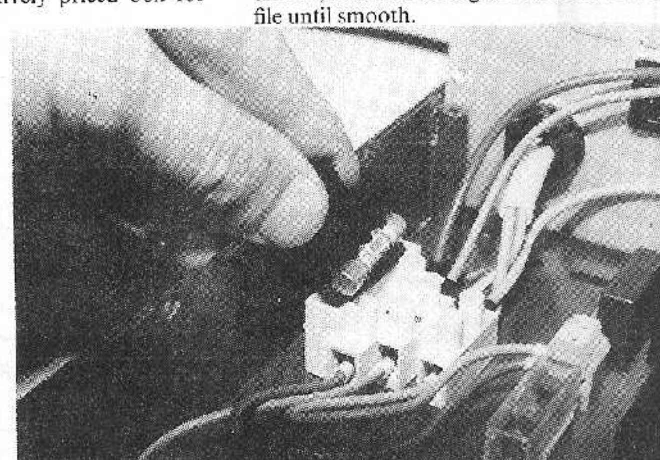
REAR PANEL

The panel at the back of the case needs punching to accept the 13A mains socket SK1 together with the 3·5mm jack socket SK2 and the mains cable inlet. The actual layout depends on the type of box used, and due care must be taken to ensure that when all parts are in place, nothing will interfere with any other parts or cause an obstruction which would prevent the box from being closed together properly.

A Q-Max punch is the best way to machine out the socket opening, however at 50mm diameter for the specified socket such a punch is a luxury. As an alternative, you could drill a ring of holes just inside the diameter of the proposed cut-out, and join them together with an Abrafile or similar, then file the edges with a half round file until smooth.



The "snubber network" RC1 mounted on the p.c.b. and heavy duty connections to the relay.



Inserting the 13A fuse into the fused mains terminal block.

Another approach would be to use a surface mounting socket, this will cover any cut-outs in the panel and perhaps avoid some of the need for neat metalworking. The case dimensions may need reviewing if a different socket is used. Use the mains socket as a template or mark out the two mounting holes for the fixing screws.

The mains cable inlet on the prototype consisted of a plastic cable gland capable of gripping the 8mm diameter 13A cable. This cushions the cable insulation and prevents it from wearing on the aluminium chassis, and also acts as a strain relief to ensure that the cable cannot be pulled out – an essential safety feature.

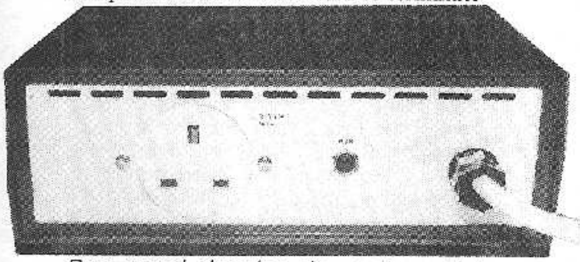
The other normally-accepted method of cable retention is to utilise a PVC grommet of 10mm internal diameter together with a nylon "P" clip. A suitable hole is also drilled in the rear panel to take the jack socket.

INTERWIRING

The final aspect of construction is the interwiring. ***It is imperative that due attention is paid to the current rating of certain wires; those which may potentially carry a full load MUST be rated at a full 13A.***

The complete interwiring diagram for the Multi-Purpose Thermostat is shown in Fig. 4. The mains inlet was fed, on the prototype, to a 16A 3-way fused screw terminal block TB2. This obviated the need for a separate fuseholder, and also the terminal block mounting screw (supplied) is automatically Earthed.

This connection block is strongly recommended (see Components List) but an ordinary 13A terminal block with a separate chassis mounting fuseholder could be used instead – in which case a one inch or 1¼in fuseholder is needed. As a further precaution against stray short circuits, crimp-on ferrules were utilised to terminate



Rear panel showing the mains outlet socket.

the stripped wires neatly prior to inserting into the terminal blocks. Continue with the interwiring as follows.

The p.c.b. mains input to the two-way block TB1 can be connected with 6A mains wire. The heavy load-bearing cables carry current between the mains inlet, via the relay to the mains socket. Use 13A rated mains cable to interconnect the relay and mains socket in accordance with Fig. 4.

The specified relay is equipped with 0·25in shrouded male blades whilst the relay coil's power is derived from the p.c.b. Terminate the relay connecting wires with crimp automotive-type female connectors, preferably fully insulating them with heat-shrink sleeve or expanding insulation tubing (see close-up photographs). It is desirable to use the mains colour code for the live (brown) and neutral (blue) wiring.

FRONT PANEL

The front panel components can be hooked up via flying leads with standard multi-stranded interconnecting wire, using several different colours to simplify the checking process later on. The

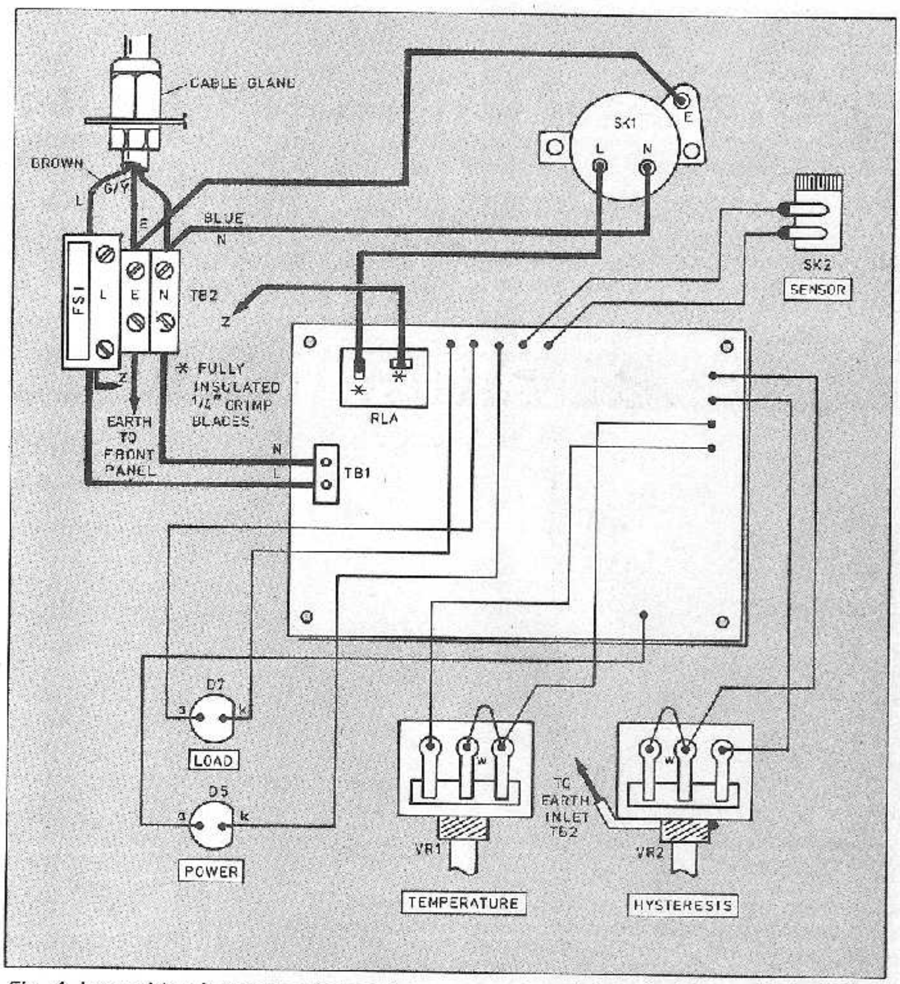
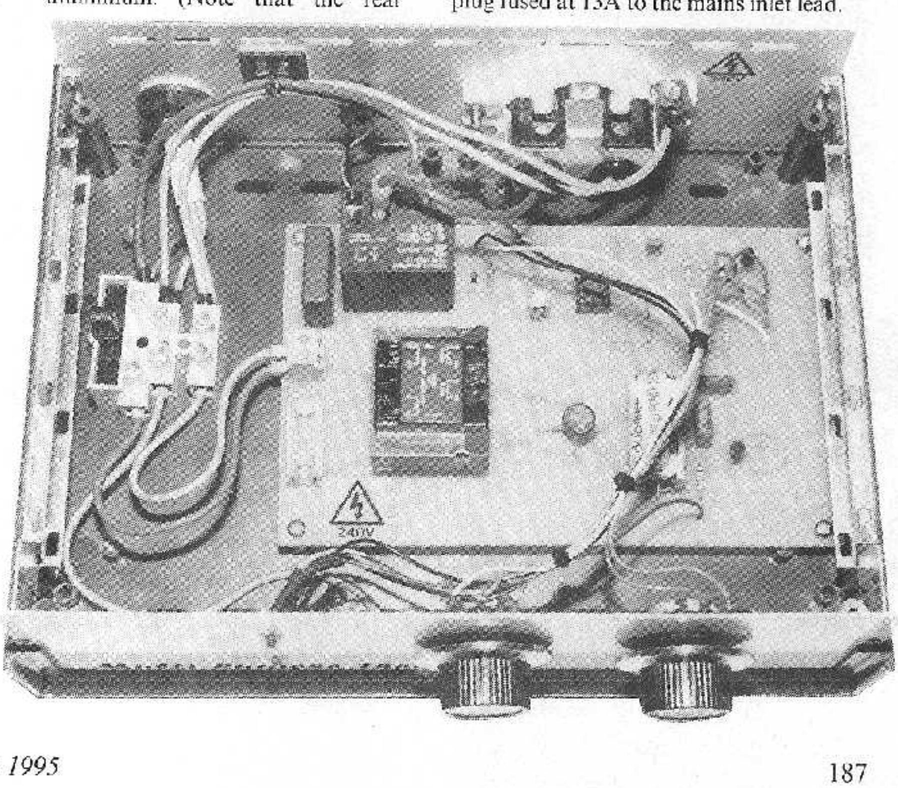


Fig. 4. Interwiring between off-board components and the circuit board. The "thick" leads are rated at 13A mains, except the two leads to TB1 which are rated at 6A.

polarity of the l.e.d.s is as shown in Fig. 4.

Precautions must be taken to ensure that all the metalwork of the case is earthed soundly. A large size (10mm internal diameter) crimp ring terminal was used on the prototype, being placed under one of the potentiometer mounting bushes to form an electrical contact with the aluminium. (Note that the rear panel is automatically earthed through the mains socket mounting screws which effectively connect to the panel.)

After connecting all flying leads in accordance with Fig. 4., the printed circuit board can be fitted to the base of the housing, and **it is essential that fully insulated hardware is used here.** Typically, p.v.c. spacers with short self tapping screws at each end can be utilised. Finally, fit a plug fused at 13A to the mains inlet lead.



PROBE

Choose which type of probe you require – it's possible to adapt the probe design for measuring free air temperature or for immersing in liquids. The prototype of a simple air temperature probe is shown in Fig. 5a.

A cheap bead thermistor was soldered to a piece of tag strip which was mounted in a small plastic box measuring 70mm × 49mm × 25mm. This has a pattern of large holes drilled into the front (finished off with a countersinking bit) to allow the thermistor to monitor ambient air; connection to the main unit was performed with a screened lead one metre long, terminated in a 3·5mm plug, but a much longer connecting lead could be used in practice.

A suggestion for a liquid probe is given in Fig. 5b. This time a small glass phial may be used, such as an aftershave or perfume sampler. Leads could be soldered directly to the thermistor, ensuring they are fully insulated with sleeving.

After positioning the bead in the bottom of the phial, embed it with potting compound or silicone rubber sealant, or leave the container unfilled and simply ensure that the cable exit is completely waterproof. Note that some potting compounds contain hazardous components (cyanide, actually) and the instructions must be followed very carefully.

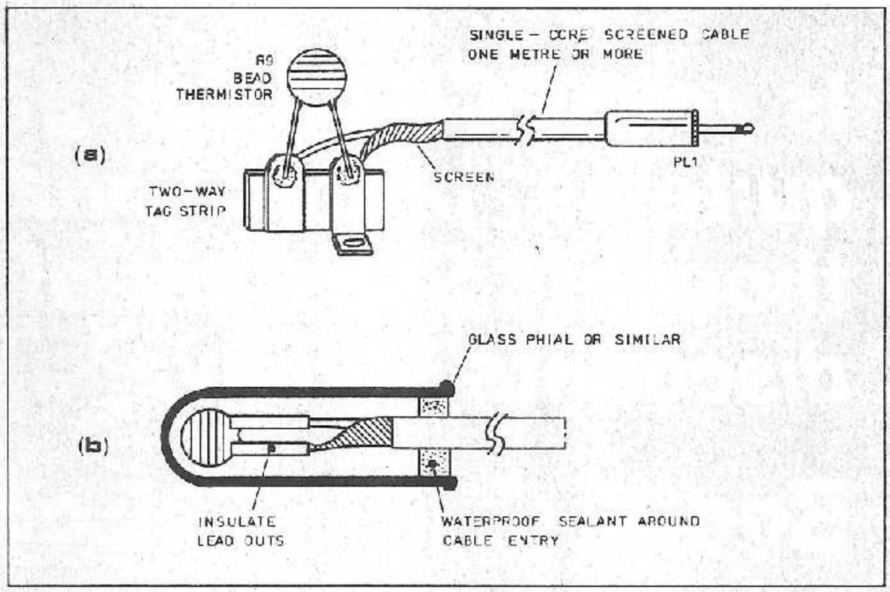


Fig. 5. (a) Ambient temperature sensor for mounting in a small box, with ventilation holes and (b) suggestion for an immersible probe for liquids.

TESTING

Prior to switching on, check through all interwiring carefully to ensure it conforms with the diagrams. Plug the temperature probe into the thermostat and set the potentiometers to mid-way.

Probably the best way to proceed after construction is to bench test the unit with a d.c. bench power supply. If available, clip a 15V to 17V d.c. (approximately) supply across the smoothing capacitor, observing polarity. There is no need to plug any heater load into the mains outlet.

Correct operation can be confirmed with a couple of quick voltmeter readings, measured with reference to 0V: the +12V regulator output was +12·09V and the reference voltage at IC3 pin 2 was +5·98V, as noted on the prototype. Check that rotating the potentiometer(s) causes the relay to switch in and out.

Warming the thermistor with a hairdryer should encourage the relay to switch out. Freezer aerosol will help cool it, if available (though the one the author used ruined the plastic finish of the prototype sensor!).

Before proceeding further, close up the case to avoid accidental electric shock and plug the unit into the mains, using an ELCB/RCD (Powerbreaker) if available. Upon powering up at the mains, the power l.e.d. D5 will illuminate, and then the relay should be heard to click on and off when the Temperature control is rotated. This indicates that the unit is ready for use. As a final check, plug in a suitable load which will operate when the relay is on.

CALIBRATION

Depending on how critical your application is, it may not be necessary to calibrate the temperature control knob. For the simple control of domestic electric heaters, for example, it may be perfectly acceptable to simply mark the dial 1 to 10 and then set the control from experience. If you do need to calibrate the control knob then it is necessary to refer the thermistor against a known temperature.

If the immersible probe is used, then possibly insert it into a bowl of iced water along with a thermometer and then compare the temperature readings against the control knob settings.

Rotate the control until the relay clicks off: read off the thermometer and calibrate the dial accordingly. Repeat this at a variety of temperatures. The Hysteresis control is best disconnected for this initial setting up, by temporarily unsoldering a flying lead on VR2.

If you have assembled the thermistor to measure air temperature, as per the prototype, then it's possible to simulate various temperatures using a cool box filled with ice packs, with the probe inside and a thermometer alongside it. Let the temperature drop down to near freezing point and then remove the ice box lid – allow the temperature to climb gradually and calibrate the setting of the control knob when the relay clicks, against the readings of the thermometer.

Again it is best to unhook the hysteresis control during setting up, to avoid any misleading errors. A digital thermometer was used against the prototype and the general range of the design was shown to be approximately +2 to +30 degrees Celsius. The Multi-Purpose Thermostat is then complete and ready for use.

FURTHER NOTES

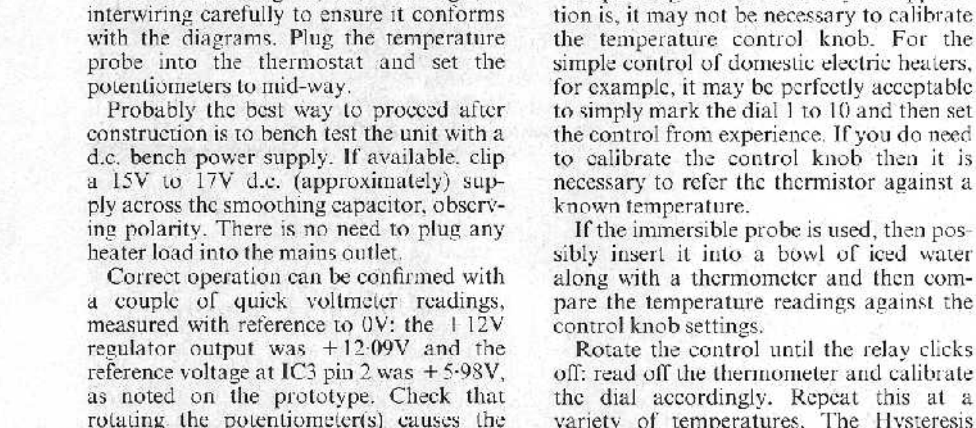
When setting up the Thermostat in its intended application, it is worth experimenting with the thermistor position to obtain the best overall effect. Obviously hot air rises and if the Multi-Purpose Thermostat is being used to sense room temperatures, then if the thermistor is placed too low down it may be "fooled" by the lower temperatures – or if it is too high or too close to the heater the thermostat may switch off prematurely. Some initial trial and error may be needed to obtain the best results, and the Hysteresis control may help to compensate as explained earlier.

Although the prototype design did not include a mains on/off switch, one can easily be incorporated into the reader's own version if desired. A double-pole rocker or toggle switch, capable of carrying the FULL mains load current, can be inserted into the circuit by connecting the mains Live and Neutral mains inputs to the poles of the switch, and then connect the wipers of the switch to the mains inlet terminal block.

Furthermore, a "bypass switch" can easily be incorporated by adding a single-pole mains rated switch in parallel with the relay contacts, then the heater can be forced to operate full-time independently of the thermostatic control.

If you wish to omit the Hysteresis control VR2, it is still best to include a degree or two of feedback in the op.amp circuit to avoid jitter. Change resistor R6 for a value of roughly 220 kilohms and then link the two adjacent take-off points for VR2 together on the p.c.b. with a jumper wire. In effect, this shorts out VR2 and places a 220 kilohm resistor in the feedback loop.

You will find that the Multi-Purpose Thermostat can be readily adapted for many temperature control applications. □



Suggested construction for the "air temperature" probes.